

ANALYSIS OF FRACTURE TOUGHNESS MODE-I OF TAPERED DOUBLE CANTILEVER BEAM

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ABSTRACT

Composite Materials are used in the making of structural components, marine components; automobile components, aerospace components and its application are widespread throughout various engineering fields. The main aim focused is about finding the rigidity of the materials under varying width with uniformity and to determine the point and region where the crack of mode - I propagate. To determine the crack length, an advanced screening system is required. But in case of width tapered double cantilever beam, the load becomes constant once the crack gets initiated. The width tapered double cantilever beam test was carried out for different mid layer materials and various taper ratios of 2.5, 3 and 4. The specimen has Carbon-Carbon and Carbon- Glass materials are kept as the mid layer. The fracture resistance capacity increases with the taper ratio. In this, the Carbon- Glass interface mid layer had more fracture energy than the Carbon- Carbon mid layer specimens. The fracture resistance capacity increases with orientation. The experiment result is compared with the FEA result. The fatigue life of carbon glass mid layer with 45-degree orientation is studied.

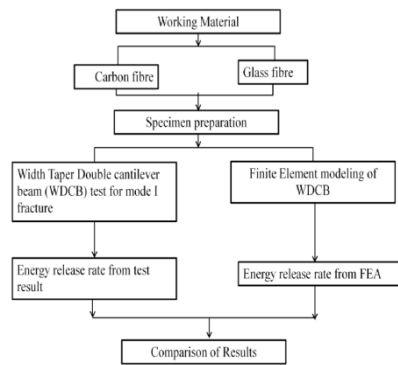
KEYWORDS: *Crack, Fatigue, Carbon-Glass & Composites*

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INTRODUCTION

To conduct the double cantilever beam test on the linearly varying width tapered specimen for three different taper ratio's and find the effect of mid layer orientation and the effect of mid layers material and the validation of the same by Finite element analysis using Ansys.

The composite plates are manufactured by the hand lay-up method from Glass, Carbon fiber reinforcement with epoxy resin for laminate. By hand layup method carbon/glass epoxy laminate is prepared. The carbon and glass fiber mats are cut into required shape and size. Take resin as 50% of the weight of the fiber and 10% of hardener mixed with the resin.[1] The epoxy is mixed with hardener and is shaken continuously. A Teflon sheet is placed on a glass piece and the epoxy hardener mixture is pasted on the sheet. Then the fibers are placed one over the other by applying the epoxy hardener mixture [2]. The Teflon sheet is kept at the mid layer for the initial crack and then the remaining upper laminates are placed by pasting the epoxy hardener mixture one by one.

**Figure 1(a): Process Methodology****Figure 1(b): Specimen with Taper Ratio 3:1**

The Teflon sheet is placed over the last fiber after applying the paste. The stacking sequence of the specimen prepared is listed in Table 1. For testing the specimen, sheets of two types with the mid layer earlier mentioned (carbon –glass, and carbon-carbon) were prepared [3]. The laminate prepared using hand lay-up method is cured in atmospheric condition for 4 hours and then placed in the bottom plate of the Compression molding machine. Before placing the laminate in the bottom plate, a wax is applied to the bottom plate.

Table 1: Stacking Sequence

S. No	Specimen Stacking Sequence
1	G0/C0/G0/C0//G0/C0/ G0/C0
2	G0/C0/G0/C0// C0/ G0/C0/G0
3	G0/C0/G0/C30//G30/C0/ G0/C0
4	G0/C0/G0/C30// C30/G0/C0/G0
5	G0/C0/G0/C45//G45/C0/ G0/C0
6	G0/C0/G0/C45//C45/C0/ G0/C0
7	G0/G0/G0/ G0// G0/G0/G0/ G0
8	G0/G0/G0/G45//G45/G0/G0/G0

The compression molding machine consists of the base plate (bottom plate) and a movable plate (top plate). Both the plates are heated to 70° C. The top plate of the Compression molding machine is brought down using the hydraulic cylinder and a pressure of 70Kg/cm² is applied to the laminate placed between the plates [4].

The laminate is allowed to stay in the compression molding machine for 10 minutes, after which the top plate is moved to its initial position and the compressed laminate is taken out. As soon as the laminate is taken out, the Teflon sheets that were placed in the hand lay-up method on both sides of the laminates are removed [5]. After that, those specimens are taken and the required shape (different taper ratios) of the final specimen is drawn in the specimen and is cut.

The final work piece, the three different specimens, the taper ratio of 2.5:1, 3:1 and 4:1 is obtained. These were then cut as per the taper ratio required. The different specimens are taken and two small holes are drilled at the smaller width section [6]. The padlock is fitted to the specimen on both sides and fixed to it with screws, washers, and nuts.

Compression Moulding Machine The hinges are fixed to the end of the beams and the hinges are connected to the jaws of the Universal testing machine. The double cantilever beam test was then carried out on these specimens on a Universal testing machine. The figure 2 shows the three different taper ratios. The first one is the taper ratio of 2.5:1.

The length of all the specimens are the same and it is 110 millimeters.

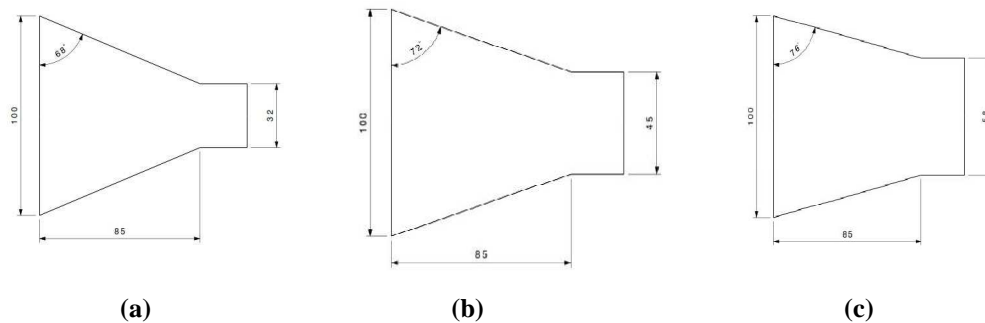


Figure 2(a): Specimen with Taper Ratio 2.5:1
(b): Specimen with Taper Ratio 3:1
(c): Specimen with Taper Ratio 4:1

In the first specimen, the angle is 68° and so the width at the smaller side is only 32mm. The second one is the specimen with a taper ratio 3:1. Here, the angle is 72° and the width at the smaller side is 45 mm. The last one is the specimen having a taper ratio 4:1. The angle is 76° and the width at the smaller side is 58 mm [7].

The specimen is obtained by stacking the laminates in series one above the other and a Teflon sheet is placed at the mid layer for the initial crack. Then the specimen is cut into the required shape and the padlock is fitted to the edge of the smaller width section and is tightened with screws and bolts [8]. The padlocks are the one which is to be inserted in the upper and lower jaws of the universal testing machine which the most common is testing machine used for double cantilever beam test is the universal testing machine.

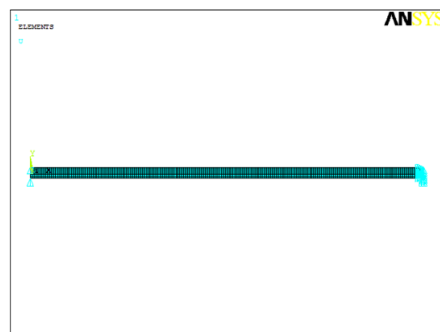


Figure 3: Meshed Beam

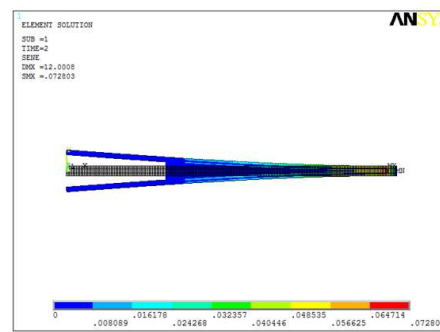


Figure 4: Delamination of WTDCB

The machine must be able to apply the force quickly or slowly enough to properly mimic the actual application. Finally, the machine must be able to accurately and precisely measure the gauge length and forces applied. Universal Testing Machine The universal testing machine used here is the INSTRON 3369. It has the capacity of 50kN.

Modeling of the specimen is done using the 2D plane model in ANSYS 14. The crack is induced in the model at the center layer. The length of the specimen is 110mm and the initial crack length is 45mm. Material Property of the specimen as obtained from the experiments are given as the input parameters for the finite element analysis [9].

The meshing of the model is done using PLANE 182 element and INTER 202 elements are given along the crack path. Model has meshed with 1200 PLANE 182 and 140 INTER 202 elements [10]. Displacement boundary condition is applied at the end of the beam as shown in Figure 3. Meshed model of the Specimen The meshed model is fixed at the right

end by arresting all degrees of freedom of the nodes as shown. Force is applied at the left end of the beam to simulate the WDCB test.

T we can change the wedge action grips based on the shape of the specimen. The frequency can be adjusted in this fatigue machine from .25 hertz to 15 hertz in safe running condition. We can also adjust the amplitude level. The fatigue action, the cyclic loads are controlled by hydraulic actions[11]. This 8802 has higher capacity fatigue testers feature precision-aligned, high stiffness load frames that encompass a broad range of static and dynamic test applications from basic metals to larger scale component testing.

The inter laminar fracture toughness of the width tapered double cantilever beams are found and the experimental results are compared with the finite element analysis and the fatigue life of best specimen is found. The fractographic view of the fractured carbon and glass fibers are taken.

For Carbon Glass Midlayer

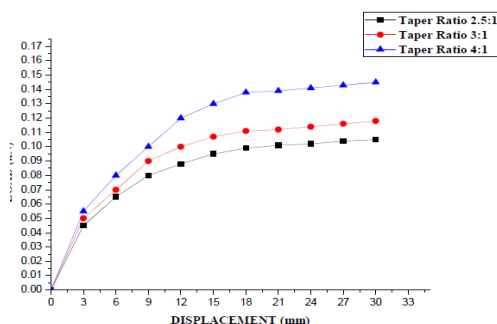


Figure 5: Different Taper Ratio

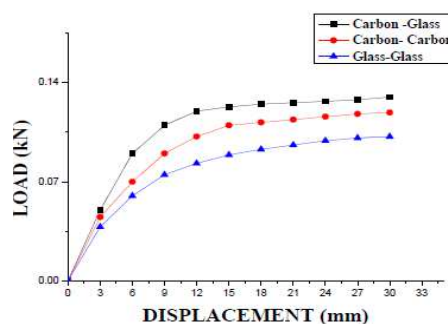


Figure 6: Orientation

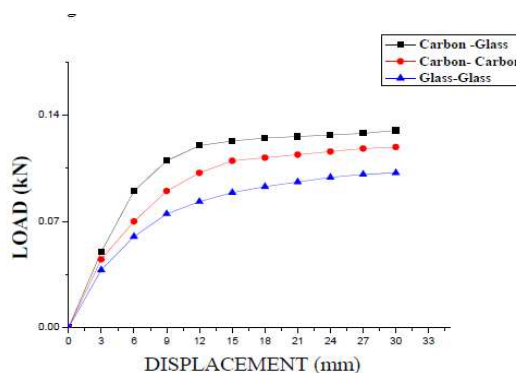


Figure 7: Displacement

The load versus displacement curve is plotted for three different taper ratios (2.5, 3, 4). The figure 5 shows the inter-laminar fracture toughness increases with the taper ratio. This is because the area of contact between the mid layers keeps on increasing with the taper ratio. [12]

Now, let compare the effect of orientation. There are 3 different orientations (0° , 30° , and 45°). This is studied by having carbon-carbon as mid layer and carbon glass as mid layer. Figure 6 Fractured Load for Carbon – Glass Mid layer The figure 6 and 8 shows that the specimen having 45-degree orientation in the mid layer had more interlaminar fracture toughness when compared to the specimen containing 0-degrees and 30-degrees orientation in the mid layer. The interlaminar fracture toughness is directly proportional to the orientation.

For Carbon-Carbon Midlayer

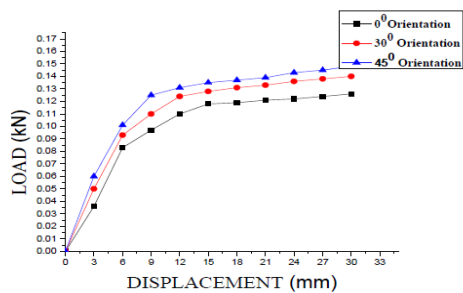


Figure 8: Orientation

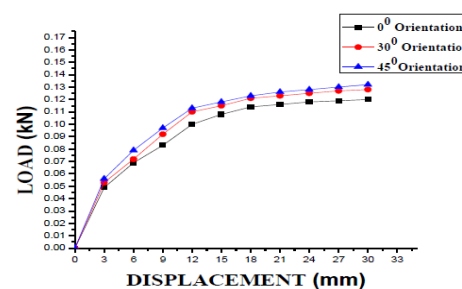


Figure 9: Displacement

The results obtained in the Finite element analysis for Carbon-Carbon (0°) as mid layer is shown. Figure 4 Delaminating of the WTDCB shows the delaminating of the carbon-carbon 0 in zero degrees orientation. The strain energy is more at the final crack tip [13]. The crack growth path is the same as that obtained from the experimental result.

SEM IMAGES The mid layers of the specimen after the mode-I fracture is analyzed under the SEM test to know the fiber failure. A small square piece of side 15mm in both carbon and glass mid layer is cut from the fractured specimen. The small square specimen is cut through water jet machining. The water with sand at a pressure of 3600 bar pierces the specimen and the small square specimen of side 15mm is obtained.

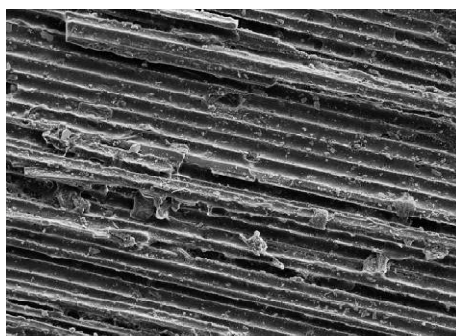


Figure 10: SEM of Carbon Glass

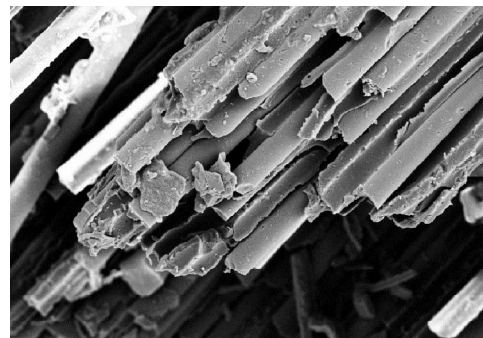


Figure 11: SEM of Carbon- Carbon

Then the specimen is undergone FESEM test and the fiber failure is obtained. Figure 10 Fracto graphic view of Fractured Surface of Carbon-Epoxy figure 11 shows the SEM images of fractured carbon fiber at 640 to 760 magnification range. The fiber bridge is formed and fiber breakage has occurred.

SEM OF GLASS FIBRES figure 11 shows the SEM images of fractured carbon fiber at 1270 magnification range. The fiber bridge is formed and fiber breakage has occurred. Here, the figure clearly shows the glass fibers failures due to breakage of fibers. The carbon fiber with glass fiber bonding is seen clearly in these images.

If the loads are above a certain threshold, microscopic cracks will form at the stress concentrators such as the surface, persistent slip bands (PSBs), and the grain interfaces. Eventually when a crack will reach a critical size, and the structure will suddenly fracture. The fatigue test is carried for carbon glass and mid layer with 45° orientation.

Table 2: Energy Release Rate Comparison

S. No	Specimen	Experimental Energy Release Rate (N/mm)	Energy Release Rate In FEA (N/mm)	Error %
1	Carbon – Carbon (45°)	0.2737	0.3023	10.45
2	Carbon – Glass (45°)	0.5792	0.6276	8.36
3	Carbon - Carbon(0°)	0.2512	0.2853	13.57
4	Carbon - Glass(0°)	0.2645	0.2836	7.22
5	Carbon - Glass(30°)	0.2965	0.3245	9.44
6	Carbon - Carbon(30°)	0.2645	0.2967	12.17

The load given to the specimens are 58, 65, 87 and 100 newtons which are (40, 50, 60 and 70) % of its Crack initiation load. The specimen is fitted to the fatigue machine and the load is given and the frequency is started at 1 hertz and slowly increases up to 5.5 hertz. Figure 6 S-N curve for 45° orientation of carbon glass mid layer The (S-N) graph is drawn for the carbon glass mid layer of 45° orientation.

The lifetime of the specimens for the three different loads is noted. The lifetime increases when the load is decreased. The three points are taken and the graph is drawn. The endurance limit of this specimen is nearly .4 MPa.

CONCLUSIONS

The interlaminar fracture toughness is found through the mode-I fracture test for width tapered double cantilever beam having different taper ratio, different middle layers and different orientations. The following conclusions are made:

- The effect of Taper ratio In this specimen having the ratio 4:1 is found to have crack initiation load of 145 N where as the specimen with the ratio 3:1 is found to have a crack initiation load of 125 N which is 11.72% lower. Hence the specimen with taper ratio 4:1 is found to have higher crack initiation load
- The effect of middle layer The specimen with the carbon glass middle layer is found to have more fracture toughness as compared to carbon-carbon middle layer. Specimen with carbon-carbon middle layer is found to have a crack initiation load of 120 N while the carbon glass is found to have a load of 130N, which is 7.6% higher.
- The effect of orientation The specimen with 45° orientation is found to have crack initiation load of 130N, while the specimen having 00 orientation is having a crack initiation load of 118N which is 8.60% lower.
- From the fatigue test, it was found that the endurance limit of the specimen is found to be 0.4 MPa
- The energy release rate obtained from experimental and FEA analysis differ by an average of 10%.

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